INSULATED BARRIERS AND METHODS FOR PRODUCING SAME

Related Applications

[0001] This application claims priority from United States Provisional Patent Application Serial Number 60/253,795, filed November 29, 2000 and United States Patent Application Serial No. 09/972,163, filed October 4, 2001, which claims priority from United States Patent Application Serial No. 09/809,793, filed March 16, 2001, which claims priority from United States Provisional Patent Application Serial Number 60/195,165, filed April 6, 2000, the disclosures of which are incorporated herein by reference.

Field of the Invention

[0002] The present invention relates generally to insulated barriers for temperature-sensitive or thermally-controlled applications. More particularly, the present invention relates to evacuated insulated barriers comprising a substantially gas-impermeable and rigid encapsulating structure with an insulating core material that is formed *in situ* within the encapsulating structure and that supports the walls of the

encapsulating structure. This invention also relates to methods for producing such insulated barriers.

Background of the Invention

[0003] In many industries, accurate and long-lasting temperature control within packaging, storage, and transportation systems is crucial. Such temperature-sensitive applications include, for example, refrigeration equipment and insulated products for the consumer market, and containers for the shipment and storage of biomedical products. In some applications, such as the shipment of biomedical products, the temperature must be controlled at sub-zero or cryogenic conditions. However, existing shipping and storage containers, which are typically made of pre-formed polystyrene or polyurethane core materials, provide inadequate insulation and require a substantial quantity of coolant, such as dry ice. In addition, they are often expensive and non-disposable. And, while the overall thermal conductivity of a thermally insulating device can be further decreased by increasing the thickness of the insulating material, the effectiveness of the insulator decreases significantly as the surface area of the device is increased. See, "Common Application Misunderstandings and the Role of Engineering Assistance in Educating the Vacuum Insulation Customer" Vuoto, 28(1-2), pp. 47-50 (January-June 1999).

[0004] In general, efforts to enhance the performance of thermal insulation devices have focused on decreasing the thermal conductivity (k) of insulating materials (also expressed in terms of its inverse, "R-value"). The lower the thermal conductivity, the lower the overall heat transfer and thus, the better the insulator. These efforts have focused on the reduction of some, but not all, of the heat transfer mechanisms (heat transfer by

solid conduction, heat transfer by gas conduction and heat transfer by radiation), and have not been successful.

[0005] For example, there are two basic ways in which heat transfer by solid conduction can be reduced. One way is to decrease the density of the insulating material. The other way involves using an insulating material of low thermal conductivity and making irregular connections within the material so that there is no straight or short path through the material from one side of the insulator to the other. This 'tortuous path' method typically means that the solid material also contains small, open cells within it that are separated by irregular shaped and thin-wall sections that resemble a sponge-like material. Thermal insulation devices that reduce solid conduction in these ways have thermal conductivities typically in the range of about 15 to 70 mW/m*K. For example, polystyrene and polyurethane insulation have thermal conductivities of about 23 to 70 mW/m*K which can be further reduced to about 20 mW/m*K by reducing the density. An example of a material that reduces solid thermal conductivity via the tortuous path method is an aerogel. Aerogels can have thermal conductivities as low as approximately 15 mW/m*K.

[0006] However, reducing heat transfer by solid conduction in these ways is limited. One limitation is that reducing the density of an insulating material also reduces its mechanical strength. Oftentimes, the insulating material, in addition to providing thermal insulation, is required to contribute mechanical strength and stability to an insulated barrier. Thus, the reduction in mechanical strength limits the extent to which the density may be reduced. A limitation for materials that reduce solid conduction by the tortuous path method, such as aerogels, is that suitable materials

for use in thermal insulation systems were not known until applicants' invention of United States Patent Application Nos. 09/809,793 and 09/972,163, which are incorporated herein by reference.

[0007] Heat transfer by radiation can be reduced by minimizing radiation transfer throughout the material and by minimizing the amount of radiation coming into contact with the insulating material. Radiation transfer through the insulating material can be reduced by using opacifiers. In addition, metal reflectors may be used to reflect radiation away from the insulation. The use of opacifiers and metal reflectors have been observed to reduce the overall thermal conductivity of an insulator. See, "Thermal Properties of Organic and Inorganic Aerogels" Journal of Materials Research, 9(3), pp. 731-738 (1994). Such techniques can reduce the overall thermal conductivity to about 12 to 20 mW/m*K. Examples of materials that reduce heat transfer by minimizing radiation transfer are organic aerogels, opacified aerogels, polystyrene and polyurethane. However, there is still a need to reduce thermal conduction to values below 12 mW/m*K.

[0008] Heat transfer by gas conduction results when gas molecules collide with each other and transfer heat from the "hot side" to the "cold side" of a thermal insulator. One method for reducing heat transfer by gas conduction is to evacuate the insulating space. Evacuation reduces the number of gas molecules within the insulating space, thereby decreasing the frequency of collisions with other gas molecules and with the walls of the insulating container. This reduces the heat transfer that occurs across the insulating space. Such techniques are used in vacuum insulation systems and can reduce the overall thermal conductivity to less than about 3 mW/m*K.

[0009] One type of vacuum insulation system uses two encapsulating structures, one placed inside the other, with a vacuum between. The vacuum reduces the conduction of heat from one structure to the other and thus, reduces heat transfer by gas conduction. An example of this type of vacuum insulation system is a Dewar flask. In a Dewar flask, the encapsulating structures (*i.e.*, flasks) are made of a gas impermeable material, such as glass, and their surfaces are usually lined with a reflective metal, such as aluminum or silver, to reduce the transfer of heat by radiation. Dewar flasks are commonly used to store liquefied gases, such as liquid nitrogen, and cryogenic material.

[0010] Unfortunately, this type of vacuum insulation system is not very versatile. The size and shape of the encapsulating structure must be specially designed so that the walls do not collapse under atmospheric pressure (*e.g.*, thickness and strength of the walls). Additionally, because the walls are not supported in the vacuum space, the shape of the encapsulating structure is limited to round, oval or cylindrical. Further, to maintain its insulation value, the walls must be absolutely impermeable to gas and moisture. This limits the wall material to either specially treated glass or metal, both of which have a tendency to conduct significant amounts of heat at areas where the walls are joined together (*i.e.*, "edge losses"). Moreover, Dewar flasks made of glass tend to be fragile, and those made of metal are expensive and have high solid thermal conductivities.

[0011] It would therefore be desirable to develop an encapsulating structure that combines durability (such as that of plastic) with high gas-impermeability (such as that of glass (*i.e.*, a silicon oxide) or metal). One

such combination is disclosed in United States Patent No. 4,560,075 ("the '075 patent"). The '075 patent discloses a vacuum flask in which the flask is made from a molded plastic material and coated with metal. However, such a system requires an ultra-high vacuum and plastic that is strong enough to support the flask under atmospheric pressure and under forces encountered in ordinary use. These requirements limit the geometries to those that can be readily achieved, *e.g.*, cylinders with small neck openings. In addition, strengthening the plastic increases thermal heat transfer along the walls of the flask and also, increases the flask's weight.

[0012] The combination of plastic and a metal oxide coatings ("glass coatings") has only recently become possible as a result of technological advances in film deposition processes. See, *e.g.*, United States Patent Nos. 4,847,469; 4,888,199; 5,224,441; 5,364,665 and 5,904,952. However, these processes have not been used to make encapsulating structures for vacuum insulation. Rather, they have primarily been used to make coatings in food and beverage packages, semiconductor coatings, abrasive coatings, and optical components.

[0013] Another type of vacuum insulation system uses the system described above, but includes, an insulating material placed within the vacuum space (*i.e.*, the space in between the two flasks). In the case of a Dewar flask, the vacuum space is filled with a radiative shielding material, such as aluminized MYLAR, to decrease the transfer of heat by radiation. Others, like the Dewar-like thermal coffee carafe disclosed in United States Patent No. 5,968,618 ("the '618 patent"), may be partially filled with an insulating material, such as a silica aerogel, and evacuated in areas adjacent to the insulating material.

[0014] However, in addition to the deficiencies described above, this type of vacuum insulating system further suffers in that the insulating materials that have been used do not support the walls of the structure. As used herein, the term "support" refers to the ability of an insulating material to provide structural integrity to the wall so that it does not significantly collapse under atmospheric pressure. In the absence of such support, the walls must be sufficiently thick and strong in order to withstand atmospheric pressure. However, increasing the thickness of the walls increases thermal conductivity into the coolant space.

[0015] A third type of vacuum insulation system, referred to as vacuum insulation panels ("VIPs"), are formed by wrapping a thin film barrier or envelope around a core material, and then evacuating the enclosed gases. The barrier or envelope is tightly sealed to maintain the vacuum. The core materials used in the VIP provide resistance to heat transfer and also, support the barrier or envelope. In these systems, the barrier or envelope is a non-rigid, gas impermeable material such that the diffusion of gas into the evacuated space is minimized. As used herein, the term "rigid" refers to a structure that is essentially self-supporting in its final shape prior to evacuation and in the absence of core material.

[0016] Core materials used in a VIP may be provided in varying thickness and composition. Typically, such materials are open-celled. As used herein, the term "open cell material" refers to a material in which greater than about 80% of the cells or pores are open. Materials in which less than about 80% of the cells or pores are open are referred to as "closed-celled." The amount of open pores can be calculated by measuring the absorption of liquid nitrogen or by using standard nitrogen gas adsorption measurements (BET analysis) or

helium pycnometry means. Recently, Cabot introduced a VIP containing a material known as NANOGEL™ as the core material. See, *e.g.*, http://www.cabot-corp.com/. NANOGEL™ material is a porous solid combining silica, titania and/or carbon. See, *e.g.*, http://www.nanopore.com/Vacuum_Insulation.html. Dow has also introduced VIPs containing an open-cell core material, known as INSTILL. Dow's VIPs contain a substantially open-cell, microcellular polystyrene foam. See, *e.g.*, http://www.dow.com/instill/overvw/ov5.html.

[0017] However, the core materials used in VIPs, including NANOGEL™ and INSTILL, have several deficiencies. Manufacture of the VIP requires multiple steps, including a prefabrication step and a fabrication step. In the prefabrication step, the core material is prefabricated into board stock; in the fabrication step, the core material is fabricated into the desired size and shape; and in the final step, the core material is wrapped with a barrier material and evacuated. In the time period between the prefabrication step and the final step, the core material is exposed to the environment and handling, and as a result, may be damaged even before the VIP is made.

[0018] Another problem with VIPs is their barrier material. In general, the barrier materials used to make VIPs are either plastics, metallized plastics (often produced by vapor depositions of metals), lamination-produced metal foil/plastic composites, or welded metal foils. See, *e.g.*, United States Patent Nos. 3,993,811; 4,444,821; 4,669,632; 5,376,424; and 5,897,932. Metallized films or metal foils are the main VIP barrier material used with open-celled core materials.

[0019] However, each of the known VIP barrier materials suffers from drawbacks. For example, plastics

do not fully prevent gas diffusion, and consequently, the shelf life of the VIP is reduced. Similarly, metallized films or metal foils exhibit stress cracks or pinholes, and consequently, the shelf life of the VIP is reduced. Moreover, panels made from these films and foils contain extremely rough surfaces adjacent to the seams and, therefore, gaps remain between panels when they are assembled, *e.g.*, into boxes (*i.e.*, causing edge loss). Also, because the films and foils are not rigid structures, the insulating core materials must be pre-formed into their final shapes and consequently, secondary manufacturing steps are needed to enclose them within the film or foil encapsulation structure.

[0020] Moreover, foils and films also are difficult to seal while being evacuated. For example, metal foil requires sealing techniques such as laser welding, and metallized films are typically heat sealed. In these processes, edge seals contribute to extremely rough surfaces adjacent to the sealed edge. And, face seals are difficult to achieve in a vacuum chamber environment under current manufacturing technologies. Additionally, it is difficult to obtain a flat seam while the foil or film is attached to an evacuation orifice. Furthermore, because the heat sealing process causes damage to the gas-impermeable metal coating of the plastic film, and because the resulting plastic seal is not gas-impermeable, a hermetic seal is not achieved. Finally, there is no known method for producing vacuum insulation systems using metallized films or foils in geometries other than flat, rectilinear panels.

[0021] A fourth type of vacuum insulation system is an insulated double walled barrier with a vacuum between the walls. Such vacuum insulated systems contain an insulating material placed within the vacuum space. For example, United States Patent No. 6,168,040 discloses an

insulated barrier filled with foamed glass. The insulated barrier disclosed in United States Patent No. 6,244,458 contains a VIP as the insulating material. United States Patent No. 5,971,198 discloses an insulated barrier comprising a pre-formed glass fiber pelt as the insulating material. See also, United States Patent No. 5,797,513. The insulated barrier disclosed in United States Patent No. 5,827,385 is formed by two mating and interfitting vacuum insulation panels that are pressed together. Each panel is made from a thermoformed or vacuum formed gas impermeable sheet plastics material and contains a known insulating material, such as finely divided precipitated powder silica or an open cell rigid foam made from Dow Chemical Company.

[0022] However, existing insulated barriers have several problems. First, they often use pre-formed core materials as the insulating material. Using pre-formed core materials limits the size and shape of the insulating barrier. Further, because pre-formed core materials are made independently of the insulating barrier, the insulated barrier requires secondary manufacturing operations. For example, such core materials must be first molded and demolded and then fabricated into the shape required for the intended application, and finally, the fabricated core material must be wrapped (in the case of a VIP) or placed within the insulated barrier.

[0023] Another problem with existing insulated barriers is that often the core material does not support the structure. As a result, the walls must be sufficiently thick and strong to prevent the walls from collapsing upon one another due to atmospheric pressure. However, as the thickness of the wall is increased, the thermal conductivity into the coolant space also

increases. This limits the choice of materials for the walls and the geometries of the insulated barrier.

[0024] In view of the above, there remains a need for an insulation system that provides superior thermal conductivity comprised of gas impermeable rigid walls and a core material that is formed *in situ* within the walls, and that supports the walls of the structure.

Summary of the Invention

[0025] It is an objective of the present invention to provide an insulated barrier for thermal applications wherein all three mechanisms of heat transfer are simultaneously reduced. More particularly, it is an objective of the present invention to provide an insulated barrier comprising:

(a) a first substantially gas impermeable rigid wall;

(b) a second substantially gas impermeable rigid wall;

(c) adjoining portions between said first and second walls that create an entirely closed and substantially hermetically sealed structure; and

(d) a core material between the walls that supports the walls of the structure, comprising a substantially open-cell structure or composition;

wherein said core material is formed *in situ* within said walls.

[0026] It is another objective of this invention to provide an insulated barrier comprising:

(a) a first substantially gas impermeable rigid wall;

(b) a second substantially gas impermeable rigid wall;

(c) adjoining portions between said first and second walls that create an entirely closed and substantially hermetically sealed structure; and

(d) a core material between the walls that supports the walls of the structure, comprising a substantially open-cell structure or composition;

wherein said first substantially gas impermeable rigid wall, said second substantially gas impermeable rigid wall and said adjoining portions comprise a plastic coated with a metal oxide (*e.g.*, a silicon oxide) coating.

[0027] It is another objective of this invention to provide an insulated barrier comprising:

(a) a first substantially gas impermeable rigid wall;

(b) a second substantially gas impermeable rigid wall;

(c) adjoining portions between said first and second walls that create an entirely closed and substantially hermetically sealed structure; and

(d) a core material between the walls that supports the walls of the structure, comprising a substantially closed-cell structure or composition;

wherein said first substantially gas impermeable rigid wall, said second substantially gas impermeable rigid wall and said adjoining portions comprise a plastic coated with a metal oxide (*e.g.*, a silicon oxide) coating; and

wherein said closed-cell structure or composition is a powder or granular; provided that said closed-cell structure or composition is not foam glass.

[0028] It is another objective of this invention to provide an insulated barrier comprising an evacuation-compatible core material component of variable thickness and opacification, and of low solid thermal conduction.

[0029] It is a further objective of this invention to provide an insulated barrier wherein the walls of the barrier are evacuated and sealed following the introduction of the insulating core material.

[0030] It is a further objective of this invention to provide an insulated barrier comprising a vacuum breach sensor to alert the user to a deleterious breach of the evacuated walls.

[0031] It is another objective of this invention to provide a method for producing insulated barriers.

[0032] These objectives are merely exemplary and are not intended to limit the scope of the inventions described in more detail below and defined in the claims.

Brief Description of the Drawing Figures

[0033] The present invention will be better understood by reading the Detailed Description with reference to the accompanying drawing figures, in which like reference numerals denote similar structure and refer to like elements throughout, and in which:

[0034] **Fig. 1** is a perspective view of a first embodiment of the insulated barrier of the present invention, demonstrating the invention in flat-panel form, and further having a partial breakaway section showing an internal space thereof;

[0035] **Fig. 1A** is a sectional view of a preferred form of a wall of the insulated barrier of the present invention;

[0036] **Fig. 2** is an exploded perspective view of an alternate form of construction of the first embodiment of the insulated barrier of the present invention, demonstrating the invention in flat-panel form;

[0037] **Fig. 3** is a perspective view of a second embodiment of the insulated barrier of the present

invention, demonstrating the invention in the form of a box comprising a gas impermeable encapsulating structure, and further having a partial breakaway section showing an internal space thereof;

[0038] **Fig. 4** is an exploded perspective view of an alternate form of construction of the second embodiment of the insulated barrier of the present invention, demonstrating the invention in the form of a box comprising a gas impermeable encapsulating structure, and further having a partial breakaway section showing an internal space thereof;

[0039] **Fig. 5** is a perspective view of the third embodiment of the insulated barrier of the present invention, demonstrating the invention in the form of a cylindrical gas impermeable encapsulating structure, and further having a partial breakaway section showing an internal space thereof; and

[0040] **Fig. 6** is an exploded perspective view of an alternate form of construction of the third embodiment of the insulated barrier of the present invention, demonstrating the invention in the form of a cylindrical gas impermeable encapsulating structure, and further having a partial breakaway section showing an internal space thereof.

Detailed Description of the Invention

[0041] In order that this invention may be more fully understood, the following detailed description is set forth. However, the detailed description is not intended to limit the inventions that are defined by the claims.

[0042] The present invention provides an insulated barrier having a high degree of thermal insulation. The inventive insulated barrier comprises:

(a) a first substantially gas impermeable rigid wall;

(b) a second substantially gas impermeable rigid wall;

(c) adjoining portions between said first and second walls that create an entirely closed and substantially hermetically sealed structure; and

(d) a core material between the walls that supports the walls of the structure, comprising a substantially open-cell structure or composition;

wherein said core material is formed *in situ* within said walls.

[0043] As used throughout this application, the terms "wall," "adjoining surface," "enclosure," and "barrier," along with their plurals, shall define a substantially gas-impermeable rigid encapsulation structure, or an element thereof.

[0044] The gas-impermeable rigid walls used in the insulated barriers of the present invention are made from materials that include, but are not limited to, metals; organic substrates coated with an inorganic matrix; metal coated plastics; single and multi-layer plastic barriers; sprayed, sputtered and otherwise deposited gas impermeable materials coated onto a rigid substrate. Preferably, the gas-impermeable rigid walls comprise a multi-layered plastic such as a laminate consisting of sequential layers of high density polyethylene/ethylvinyl alcohol/high density polyethylene. More preferably, the gas impermeable wall comprises an organic substrate coated with an inorganic matrix. Even more preferably, the gas impermeable wall is a plastic coated with a metal oxide coating. See, *e.g.*, United States Patent No. 6,112,695. Yet, even more preferably, the gas impermeable wall is a plastic coated with a silicon oxide coating. Unlike known insulated barriers, the insulated

barriers of the present invention contain rigid walls. As a result, they are more robust and durable than those known.

[0045] The gas-impermeable walls are preferably made as thin as possible to limit the insulated barrier's solid thermal conductivity and material weight, while remaining rigid. In one embodiment, the gas impermeable walls may be formed from an impact resistant structure. Preferably, the gas impermeable walls comprise a multi-layered plastic with walls that are about 0.005 to about 0.25 inches thick. In a second preferred embodiment, the gas impermeable walls comprise a single layer plastic, with a gas-impermeable coating, with walls that are about 0.005 to about 0.25 inches thick.

[0046] Preferably, the substantially gas-impermeable walls have several, and more preferably all, of the following properties:

1. gas permeability less than about 0.01 cc*mil/24hrs/100in^2/ATM for Oxygen;
2. solid thermal conductivity less than about 200 mW/m/K;
3. high impact resistance;
4. easily fabricated into complex shapes and sizes;
5. relatively inexpensive;
6. easily sealed under vacuum using methods such as sonic, heat, or radio frequency welding.

[0047] The core material used in the insulated barrier of the present invention supports the rigid walls and is formed *in situ* within the barrier walls. Methods for forming core materials *in situ* are disclosed in United States Patent Application Nos. 09/809,793 and 09/972,163.

[0048] Preferably, the core material comprises a substantially open cell structure, in which at least 80%

of the cells or pores are open. More preferably, the core material comprises an open cell structure in which 100% of the cells or pores are open. The core material may be in any shape or size including, but not limited to, thin films, granulars and monoliths.

[0049] Thin films and sheets are defined as a coating, less than about 5 mm thick, formed on a substrate. Granulars are defined as comprising particle sizes such that the volume is less than about 0.125 ml. Monoliths are defined as bulk materials having volumes greater than about 0.125 mls, which corresponds to a block of material having a volume greater than about 125 mm^3 (*i.e.*, 5 mm x 5 mm x 5 mm).

[0050] Suitable core materials include, but are not limited to, open cell polystyrene, open cell polyurethane and open cell foams. More preferably, the core material comprises small pore area materials, even more preferably, low density microcellular materials, and yet even more preferably, aerogels, which are described in United States Patent Application Nos. 09/809,793 and 09/972,163. Most preferably, the core material is a monolithic aerogel.

[0051] A small pore area material ("SPM") is a type of foam, which may be thought of as a dispersion of gas bubbles within a liquid, solid or gel (see IUPAC Compendium of Chemical Terminology (2d ed. 1997)). Specifically, and as used herein, an SPM is a foam having a density of less than about 1000 kilograms per cubic meter (kg/m^3) and a small pore structure in which the average pore area is less than about 500 μm^2. Average pore area, as used herein, is the average of the pore areas of at least the 20 largest pores identified by visual examination of images generated by scanning electron microscopy ("SEM"). These pore areas are then

measured with the use of ImageJ software, available from NIH.

[0052] Organic SPMs are preferred because they typically exhibit lower solid thermal conductivity than inorganic SPMs, and their precursor materials tend to be inexpensive and exhibit longer shelf-lives. Further, they can be opaque (useful to reduce radiative thermal transfer) or transparent, although such opaque foams do not require opacification. See, e.g., "Aerogel Commercialization: Technology, Markets, and Costs," Journal of Non-Crystalline Solids, vol. 186, pp. 372-79 (1995). As a result, generally, opaque organic SPMs are more desirable, especially for thermal applications in which optical transparency is not desired.

[0053] One type of SPM is a low density microcellular material ("LDMM"). Specifically, and as used herein, an LDMM is an SPM having a microcellular structure in which the average pore diameter is less than about 1000 nanometers (nm) which is determined by measuring the average pore area and then calculating the average pore diameter by using the formula: area = Πr^2. For example, an average pore area of 0.8 μm^2 corresponds to an average pore diameter of 1000 nm.

[0054] An aerogel is a type of LDMM (and thus it is also an SPM) in which gas is dispersed in an amorphous solid composed of interconnected particles that form small, interconnected pores. The size of the particles and the pores typically range from about 1 to about 100 nm. Specifically, and as used herein, an aerogel is an LDMM (and thus it is also an SPM) in which: (1) the average pore diameter is between about 2 nm and about 50 nm, which is determined from the multipoint BJH (Barrett, Joyner and Halenda) adsorption curve of N_2 over a range of relative pressures, typically 0.01-0.99 ("the BJH method" measures the average pore diameter of those

pores having diameters between 1-300 nm and does not account for larger pores); and (2) at least 50% of its total pore volume comprises pores having a pore diameter of between 1-300 nm.

[0055] The core material may be provided in a size or shape, limited only by the application (*i*.e., small box, refrigerator, cargo carrier or large wall).

[0056] The core material may further comprise an opacifier, such as carbon black, organic polymers and inorganic oxides, to reduce radiative heat transfer effects as referenced by "Thermal Properties of Organic and Inorganic Aerogels" Journal of Materials Research, 9(3), pp. 731-738 (March 1994). A preferred opacifier is carbon black.

[0057] In an alternate embodiment, the insulated barrier of the present invention comprises:

(a) a first substantially gas impermeable rigid wall;

(b) a second substantially gas impermeable rigid wall;

(c) adjoining portions between said first and second walls that create an entirely closed and substantially hermetically sealed structure; and

(d) a core material between the walls that supports the walls of the structure, comprising a substantially open-cell structure or composition;

wherein said first substantially gas impermeable rigid wall, said second substantially gas impermeable rigid wall and said adjoining portions comprise a plastic coated with a metal oxide (*e.g.*, silicon oxide) coating.

[0058] Preferred core materials of this alternate embodiment include SPMs, LDMMs, aerogels, polyurethane and polystyrene, in monolithic or granular form.

[0059] According to this embodiment, the core material may be formed *in situ* or pre-formed and placed within the gas impermeable walls or encapsulating structure. After such placement, the structure is evacuated and sealed.

[0060] In an alternate embodiment, the insulated barrier of the present invention comprises:

(a) a first substantially gas impermeable rigid wall;

(b) a second substantially gas impermeable rigid wall;

(c) adjoining portions between said first and second walls that create an entirely closed and substantially hermetically sealed structure; and

(d) a core material between the walls that supports the walls of the structure, comprising a substantially closed-cell structure or composition;

wherein said first substantially gas impermeable rigid wall, said second substantially gas impermeable rigid wall and said adjoining portions comprise a plastic coated with a metal oxide (*e.g.*, a silicon oxide) coating; and

wherein said closed-cell structure or composition is a powder or granular; provided that said closed-cell structure or composition is not foam glass.

[0061] According to this embodiment, the powder or granular is selected from the group consisting of carbon black, fumed silica, sand and the like. Preferably, the powder or granular can be compacted only to the point where the interstitial spaces are evacuable. More preferably, the powders or granulars are strong enough after compaction to support the gas barrier under evacuation.

[0062] According to this embodiment, the core material may be formed *in situ* or pre-formed and placed within the

gas impermeable walls or encapsulating structure. After such placement, the structure is evacuated and sealed.

[0063] Preferably, the insulated barrier of the present invention has a thermal conductivity from about 10 to about 7.1 mW/m*K. More preferably, the thermal conductivity is from about 7 to about 5.1 mW/m*K, and even more preferably from 5 to about 3.1 mW/m*K, and yet even more preferably from 3 to about 1 mW/m*K.

[0064] The insulated barrier of the present invention may optionally comprise a port. The port is either manufactured within the gas-impermeable wall, or is pre-formed and inserted within the wall after manufacture. Preferably, the port is manufactured within the gas-impermeable wall. The port may be permanently sealed, self-sealed or neither. Preferably, the port is rigid and is easily sealable after evacuation. The location, size and shape of the port are dependent on the intended application.

[0065] In an alternate embodiment, the present invention provides an insulated barrier comprising a vacuum breach sensor for detecting the presence of atmospheric oxygen when the vacuum has been compromised. The vacuum breach sensor may be visual or audible.

[0066] A visual vacuum breach sensor comprises a nonaqueous ionic liquid and an indicator. Nonaqueous ionic liquids are liquids at room temperature; are substantially viscous; and have essentially no vapor pressure. Nonaqueous ionic liquids useful in this invention are disclosed in United States Patent No. 5,304,615 and International PCT application WO 97/02252. Suitable nonaqueous ionic liquids include, but are not limited to, heterocyclic halides selected from the group consisting of pyridinium halides, pyridazinium halides, pyrazinium halides, imidazolium halides, pyrazolium

halides, thiazolium halides, oxazolium halides and triazolium halides, wherein each nitrogen atom in the heterocyclic ring is substituted with a (C1-C6) alkyl, and wherein the heterocyclic ring is optionally substituted with one to five (C1-C6) alkyl groups. Suitable halides are chloride, fluoride, bromide and iodide. Preferably, the nonaqueous ionic liquid is imidazolium halide. More preferably, the nonaqueous ionic liquid is N-ethyl-N'-methylimidazolium chloride or N-butyl-N'-methylimidazolium chloride.

[0067] The indicators used in the visual vacuum breach sensor of the present invention are highly soluble in the nonaqueous ionic liquid. Suitable indicators include, but are not limited to, thiazine dyes and indigo dyes. See, *e.g.*, United States Patent Nos. 5,358,876; 4,349,509 and 4,169,811. Thiazine dyes include, but are not limited to, Lauth's Violet, Azure B, Azure C, Methylene Blue, New Methylene Blue and Thionine Blue. Indigo dyes include, but are not limited to, Indigo, Indigo Carmine and Bromo Indigo R. Preferably, the dye is New Methylene Blue.

[0068] Preferably, the visual vacuum breach sensor comprises N-butyl-N'-methylimidazolium chloride and New Methylene Blue.

[0069] The visual vacuum breach sensor may be provided as a solution within the vacuum space or as a coating on the port, or on a wax-based carrier, wick and the like located within the vacuum space.

[0070] In another aspect of this embodiment, the vacuum breach sensor comprises one or more zinc oxide batteries connected to a light-emitting diode or an audible speaker.

[0071] The insulated barriers of the present invention may be provided in a variety of forms including, but not

limited to, flat panels, box shaped enclosures, cylindrical enclosures and the like depending on the application. The insulated barrier may be used for production of portable coolers, insulated beverage containers, refrigerators, biomedical shipping containers, building walls, water heaters and the like. Preferably, the insulated barrier of the present invention has a single seam, rather than the twelve seams inherent in a box formed from panels.

[0072] The figures herein described provide examples of such applications, but do not limit the scope of the invention in any way.

[0073] **Fig. 1** provides an insulated barrier **10**, in the form of a flat panel, having first gas impermeable wall **12**, second gas impermeable wall **14**, adjoining surfaces **16**, **18**, **20**, **22**, core material **24** comprising an open-cell composition or structure, port **26** through which a vacuum may be drawn, and optionally a vacuum breach sensor **28** held within insulated barrier **10** or port **26** by which the presence of atmospheric oxygen may be detected.

[0074] As shown in **Fig. 1A**, first gas impermeable wall **12** comprises inner surface **30** and outer surface **32**. Outer surface **32** preferably is an organic substrate, such as plastic, coated with an inorganic matrix, such as a metal oxide, the inorganic matrix forming inner surface **30**. It is preferable that the organic substrate be disposed outwardly with regard to insulated barrier **10**; that is, towards the direction(s) most susceptible to impact damage.

[0075] Second gas impermeable wall **14** is constructed in equivalent and compatible form as first gas impermeable wall **12**. Also, it is preferable that the organic portion be disposed outwardly; that is, towards the direction(s) most susceptible to impact damage.

[0076] Adjoining surfaces **16, 18, 20, 22** are provided between first and second walls **12, 14** to create an entirely closed and hermetically sealed structure. All adjoining surfaces **16, 18, 20, 22** are of gas impermeable materials, fabricated and oriented in a manner consistent with each other and with first and second walls **12, 14.**

[0077] Between first and second gas impermeable walls **12, 14** is provided core material **24,** preferably comprising an open-cell foam-like structure or composition.

[0078] Preferably, one or more of wall **12, 14** or adjoining surface **16, 18, 20, 22** contains port **26** through which a vacuum may be drawn. By connecting a vacuum pump and vacuum tubing to the port, a vacuum may be drawn to evacuate insulated barrier **10** and core material **24.**

[0079] Insulated barrier **10** or port **26** may also contain a vacuum breach sensor **28** through which the presence of atmospheric oxygen may be detected. Preferably, vacuum breach sensor **28** detects the presence of atmospheric oxygen when the vacuum has been compromised. Accordingly, a user of insulated barrier **10** would be able to readily and certainly determine when to replace insulated barrier **10** in order to preserve the thermal characteristics of insulated barrier **10.**

[0080] As shown in **Fig. 1,** the insulated barrier **10** of the present invention may be provided in flat-panel form. In such a form, and with core material **24** formed *in situ*, the precursor chemicals of core material **24** may be injected into the space or cavity between walls **12, 14** and adjoining surfaces **16, 18, 20, 22,** and then processed to its final form. Alternatively, holes, slots, or optionally removable portions of the insulated barrier **10** or adjoining surfaces **16, 18, 20, 22,** may be provided

which assist formation of the core material **24**. Advantageously, evacuation port **26** may be used for filling the cavity and for subsequent formation of the core material. When core material **24** has been formed, the panel barrier, along with core material **24**, is evacuated and sealed.

[0081] Shown at **Fig. 2** is an alternate form of construction of the first preferred embodiment of the present invention in the form of insulated barrier **200**. In contrast to insulated barrier **10**, insulated barrier **200** is used with core material **224** that is not formed *in situ*. Accordingly, insulated barrier **200** comprises a flat panel, similar in overall form and material to that just described above, comprising first gas impermeable wall **212** and adjoining surfaces **216, 218, 220, 222**, in combination forming bottom portion **234**. A second gas impermeable wall in the form of capping portion **214** is provided to complete the enclosure. In use, core material **224** is placed into bottom portion **234**, cured and/or compacted if necessary, and capping portion **214** is placed thereover. Bottom portion **234** and capping portion **214** are then sealed. The panel barrier, along with core material **224**, is evacuated via port **226** and sealed.

[0082] Advantageously, the flat panels described above with regard to **Figs. 1** and **2** may be combined, joined, or otherwise positioned so as to produce more complex structures and devices.

[0083] As shown in **Figs. 3** and **4**, the insulated barrier of the present invention may be provided in box-like forms, useful for storage, shipment, refrigeration products, or packaging containers. Preferably, such forms include a central cargo or storage cavity, the end

result looking much like a conventional box, but having thickened walls.

[0084] With reference to **Fig. 3**, in a second preferred embodiment, provided is insulated barrier **300** in the form of a box-like enclosure, which may comprise a continuous-wall structure. Insulated barrier **300** comprises first gas impermeable wall **312**, wall **312** further comprising wall segments **312a, 312b, 312c, 312d, 312e**; second gas impermeable wall **314**, wall **314** further comprising wall segments **314a, 314b, 314c, 314d, 314e**; adjoining surfaces **316, 318, 320, 322**; core material **324** comprising an open-cell structure; port **326** through which a vacuum may be drawn; and optionally a vacuum breach sensor **328** held within insulated barrier **300** or port **326** by which the presence of atmospheric oxygen may be detected. In such form, and with the use of core material **324** that may be formed *in situ*, precursors of core material **324** may be injected into the space or cavity between the gas impermeable walls **312, 314**, and adjoining surfaces **316, 318, 320, 322**, and then formed. Alternatively, holes, slots, or optionally removable portions of the gas impermeable walls **312, 314**, and adjoining surfaces **316, 318, 320, 322**, may be provided which assist formation of the core material **324**. Advantageously, port **326** may be used for filling the space between the walls and for subsequent formation of the core material **324**. When core material **324** has been formed, the insulated barrier **300**, along with the core material, is evacuated and sealed. Advantageously to this form, insulated barrier **300** may be constructed so as to include a central cargo or storage cavity **336**, the end result looking much like a conventional box, but having thickened walls, and being fully suitable for the carrying of a payload requiring

rigorous temperature control. This container form also allows for a single seam instead of the twelve seams that are inherent in a box formed from panels.

[0085] Shown at **Fig. 4** is an alternate form of construction of the second preferred embodiment of the present invention in the form of a box-like enclosure, intended to be used with a core material not formed *in situ*. Insulated barrier **400** comprises a box-like enclosure, similar in overall form and material to that described above, comprising first gas impermeable wall **412**, wall **412** further comprising wall segments **412a, 412b, 412c, 412d, 412e**; second gas impermeable wall **414**, wall **414** further comprising wall segments **414a, 414b, 414c, 414d, 414e**; capping portion **416**; core material **424** comprising an open-cell structure; port **426** through which a vacuum may be drawn; and optionally a vacuum breach sensor **428** held within insulated barrier **400** or port **426** by which the presence of atmospheric oxygen may be detected. Accordingly, walls **412, 414**, in combination, form bottom portion **434**. In such a barrier, core material **424** is placed into bottom portion **434**, formed and/or compacted if necessary, and capping portion **416** is placed thereon. Bottom portion **434** and capping portion **416** are then sealed.

[0086] Insulated barrier **400**, along with core material **424**, is then evacuated and sealed. Again, advantageously to this form, insulated barrier **400** may be constructed so as to include a central cargo or storage cavity **436**, cavity **436** being fully suitable for the carrying of a payload requiring rigorous temperature control. As discussed in further detail below, lid **438**, fabricated in accordance with the materials and methods of the present invention, may be provided to enclose storage cavity **436**.

This container form also allows for a single seam instead of the twelve seams that are inherent in a box formed from panels.

[0087] It will be apparent to one skilled in the art that a box-like container, of the type just described, appropriately scaled in size, and otherwise substantially as described above, may be outfitted with such apparatus so as to effectively function as a refrigerator or freezer, or combination thereof. Advantageously, the cavity may be linked via the evacuation port with the compressor or alternatively, with a vacuum pump unit substantially as described in United States Patent No. 5,765,379, so that the cavity may be continuously or periodically evacuated, and so as to maintain optimal vacuum conditions within the insulated barrier over long periods of time. Through the use of such continuous or periodic evacuation methods, the walls may be manufactured of a range of semi-permeable gas barrier materials suitable in cost and characteristics to be consistent with the requirements of the consumer market.

[0088] With reference to **Fig. 5**, in a third preferred embodiment, provided is insulated barrier **500** in the form of a round or cylindrical enclosure, which may comprise a continuous-wall structure. Insulated barrier **500** comprises first gas impermeable wall **512**, second gas impermeable wall **514**, adjoining surface **516**, core material **524** comprising an open-cell structure, port **526** through which a vacuum may be drawn, and optionally a vacuum breach sensor **528** held within insulated barrier **500** or port **526** by which the presence of atmospheric oxygen may be detected. In such form, and with the use of core material **524** formed *in situ*, precursors to core material **524** may be injected into the space, or cavity between the gas impermeable walls **512, 514,** and adjoining

surface **516**, and then formed. Alternatively, holes, slots, or optionally removable portions of the gas impermeable walls **512**, **514**, and adjoining surface **516**, may be provided which assist formation of the core material **524**. Advantageously, port **526** may be used for filling the space between the walls and for subsequent formation of the core material **524.** When core material **524** has been formed, the insulated barrier **500,** along with core material **524**, is evacuated and sealed. Advantageously to this form, insulated barrier **500** may be constructed so as to include a central cargo or storage cavity **536**, the end result looking much like a conventional cylindrical container, but having thickened walls, and being fully suitable for the carrying of a payload requiring rigorous temperature control. This container form also allows for a single seam instead of the twelve seams that are inherent in a box formed from panels.

[0089] Shown at **Fig. 6** is an alternate form of construction of the third preferred embodiment of the present invention in the form of a cylindrical enclosure, intended to be used in association with a core material not formed *in situ*. Accordingly, insulated barrier **600** comprises a cylindrical enclosure, similar in overall form and material to that described above, comprising first gas impermeable wall **612**, second gas impermeable wall **614**, capping portion **616**, core material **624** comprising an open-cell structure, port **626** through which a vacuum may be drawn, and optionally a vacuum breach sensor **628** held within insulated barrier **600** or port **626** by which the presence of atmospheric oxygen may be detected. Accordingly, walls **612**, **614**, in combination, form bottom portion **634**. In such form, core material **624** is placed into bottom portion **634**, formed and/or

compacted if necessary, and capping portion **616** is placed thereon. Bottom portion **634** and capping portion **616** are then sealed. Insulated barrier **600**, along with core material **624**, is evacuated and sealed. Again, advantageously to this form, insulated barrier **600** may be constructed so as to include a central cargo or storage cavity **636**, cavity **636** being fully suitable for the carrying of a payload requiring rigorous temperature control. As discussed in further detail herein below, lid **638**, fabricated in accordance with the materials and methods of the present invention, may be provided to enclose storage cavity **636**. This container form also allows for a single seam instead of the twelve seams that are inherent in a box formed from panels.

[0090] In accordance with a method of the present invention, an insulated barrier may be prepared by providing a gas impermeable enclosure having at least one space, or cavity, therein and a gas evacuation port. With the use of a core material formed *in situ*, the precursors for a core material are injected into a space or cavity between the walls of the gas impermeable enclosure, and then formed. The evacuation port optionally may be used for forming the core material. When the core material has been formed, the enclosure, along with the core material, is substantially evacuated of gas and sealed. Optionally, an oxygen vacuum breach sensor is provided within a cavity space or the evacuation port.

[0091] In accordance with an alternate method of the present invention, used in association with a core material not formed *in situ*, an insulated barrier may be manufactured by providing a gas impermeable enclosure having at least one space or cavity therein, forming a bottom portion, a capping portion, and a gas evacuation

port. The core material is placed into the bottom portion of the enclosure, formed and/or compacted if necessary, and the capping portion is placed thereon. The bottom portion and the capping portion are then sealed. The enclosure, along with the core material, is substantially evacuated of gas and sealed. Optionally, an oxygen vacuum breach sensor is provided within the cavity space or the evacuation port.

[0092] When the insulated barrier of the present invention is provided in a form having a central cargo or storage cavity, such as a shipping box or cylinder, a refrigerator, or the like, a lid, top, or door-like construct, best seen as lid **438** in **Fig. 4** or as lid **638** in **Fig. 6**, may be provided to enclose the storage cavity **436, 636**. With such an arrangement, it now will be apparent that the lid, top, or door-like construct preferably is fabricated in accordance with the materials and methods of the present invention.

[0093] It will now be apparent that the insulated barrier of the present invention advantageously may be used for production of portable coolers, insulated beverage containers, refrigerators, biomedical shipping containers, building walls, water heaters and the like. Through the use of appropriate insulating materials such as those described hereinabove, appropriately low internal pressures, and appropriately opacified materials, the insulated barriers of the present invention may operate under conditions of extreme cold or heat, and even under cryogenic conditions, while maintaining those conditions for periods of time heretofore unachievable.

[0094] It is readily apparent that, not only does the insulated barrier of the present invention offer benefits in temperature control, it provides ancillary benefits

such as reduced transportation and staging costs, reduced refrigerant costs, increased thermal insulation, increased cargo space with respect to effective refrigerant volumes, decreased package sizes and weights per effective insulation unit, along with attendant environmental benefits in each category.

[0095] In order that this invention may be better understood, the following examples are set forth.

Examples

Preparation of Inorganic Coated Plastic

[0096] Blow molded box-like polyethylene terephthalate glycol (Eastar 6763 PETG Copolymer) containers, with inner and outer walls approximately 0.060 inches thick, were provided with outer dimensions of approximately 15 in. x 10 in. x 9 in. and inner dimensions of approximately 13 in. x 8 in. x 6 in. in accordance with **Fig. 3.** An inorganic coating was then applied in accordance with United States Patent Nos. 5,516,555; 5,904,952; 6,112,695 and 6,180,191. This provided an insulated barrier container with only 28 inches of seam whereby the solid thermal conductivity of the gas-impermeable barrier was approximately 21 mW/m*K. A comparable container made from flat panels would consist of approximately 116 inches of seams.

Preparation of Vacuum Insulated Container

[0097] The container described above was provided with a port located on the bottom outside surface as indicated by **Fig. 3**, wall segment **312e**. The core material was formed within the walls of the container in accordance with United States Patent Application Nos. 09/809,793 and 09/972,163. Precursor chemicals for the core material were poured into the barrier walls of the container and

allowed to cure. Holes were drilled at the top flange of the container as indicated by **Fig. 3**, surfaces **316**, **318**, **320** and **322**, to allow for drying of the cured precursor materials and formation of the core material within the barrier walls. The holes were then plastic welded closed and the container was evacuated through the port, such that the interior space of the barrier walls was maintained under a pressure of approximately 100 mTorr.

Preparation of Vacuum Breach Sensor

[0098] A stock solution was prepared by dissolving 0.094 g of New Methylene Blue (Aldrich Chemical Co.) in 50 mL water. An aliquot of the stock solution (0.3 g) was added to a glass vial equipped with a serum cap, followed by 2 g ethanol, 0.5 g triethylamine and 0.5 g propanal. The resulting dark blue solution was immersed in a -78 °C cooling bath, degassed by piercing the serum cap with a needle interfaced to a vacuum system, and back-filled with a nitrogen atmosphere. The blue solution was allowed to stir for 18 hours at which point the color changed to a much lighter blue color. Then, 1 mL of N-butyl-N'-methylimidazolium chloride (Aldrich Chemical Co.) and 0.5 g each of triethylamine and propanal were added. The solution was degassed as before and allowed to stir under nitrogen until the blue color gave way to a light yellow-orange color. In general, the triethylamine/propanal treatment was used as necessary to reduce the dye to the leuco form. At this time, the solution exhibited a pale yellow or light orange color.

Testing Methods and Results

[0099] The vacuum insulated container described above was filled with 2.2 kilograms of dry ice and a fiberglass mat was placed on top. The temperature was measured using a thermocouple located half-way down the inner wall

of the vessel, and the ambient temperature of the room was also monitored using a separate thermocouple. The pressure of the interior space of the container walls was approximately 20 mTorr and the container was cooled to approximately -77 °C with the dry ice. After 133 hours, the temperature recorded by the inner thermocouple had increased by approximately 7° to -70 °C. At this time, the container was opened and found to contain approximately 300 grams of dry ice. From these data it was calculated that the overall thermal conductivity of the container had an upper limit of about 4.4 mW/m*K.

[0100] To test the performance of the vacuum indicator, a vial of the vacuum breach sensor described above was opened to air. Within five minutes the surface of the viscous liquid began to develop a blue-green color. Within 30 minutes the entire solution was a deep blue-green color. A sample held at a pressure of approximately 0.1 Torr retained its pale yellow-orange color indefinitely.

[0101] While particular materials, formulations, operational sequences, process parameters, and end products have been set forth to describe and exemplify this invention, such are not intended to be limiting. Rather, it should be noted by those ordinarily skilled in the art that these disclosures are exemplary only and that various other alternatives, adaptations, and modifications may be made within the scope of the present invention. Accordingly, the present invention is not limited to the specific embodiments illustrated herein, but is limited only by the following claims.

[0102] All references cited within the body of the instant specification are hereby incorporated by reference in their entirety.